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PROVISIONAL APPLICATION FOR PATENT COVER SHEET
This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

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☐ *Additional inventors are being named on the _____ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (280 characters max)

MULTI-USER DETECTION IN CDMA SYSTEMS

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

MULTI-USER DETECTION IN CDMA SYSTEMS

FIELD OF THE INVENTION

[0001]   The present invention relates to multi-user detection in Code Division Multiple Access (CDMA) systems.

BACKGROUND AND SUMMARY OF THE INVENTION

[0002]   Code Division Multiple Access (CDMA) is based on spread-spectrum technology and is a dominant air interface for the proposed modern 3G and 4G wireless networks. The transmitted CDMA signals propagate through noisy multipath fading communication channels before arriving at the receiver of the user equipment (UE). In contrast to classical single-user detection (SUD) computational techniques, which do not provide the requisite performance for modern high data rate applications, multi-user detection (MUD) approaches require a lot of a-priori information not available to the UE.

[0003]   The conventional detection schemes for CDMA signals only exploit second order statistics among user codes. Practically, however, the underlying user data symbol sequences are in general mutually (near-) "independent". This is a key assumption, which propels the application of info-theoretic learning approaches such as information maximization and minimum mutual information to the realm of CDMA. The use of these computational techniques is justified since a wide sense stationary slowly fading multipath CDMA environment can be conveniently represented as a linear multi-channel convolution model.   The

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received CDMA signal can be considered as a sum of several non-gaussian random variables generated by the linear convolutive transformations of statistically (near-) independent component user variables. This linear transformation accounts for the user spreading codes, the cell scrambling codes (in case of a cellular architecture), multiple channel paths and slowly fading channel effects. The present invention estimates a linear transformation to counteract, as "optimally" as possible, the effects of a first transformation --resulting in the recovery of the original user signals under the constraint of knowing only the user's signature code (and the corresponding cell scrambling code for a two stage implementation).

[0004] Blind Source Recovery (BSR) is the process of estimating the original "independent" user-specific symbol sequences independent of, and even in the absence of, precise system/channel identification. In typical downlink signal processing, where many of the system parameters are unknown, including the codes for co-existing users at any instant of time, one can use the blind techniques for better estimate of the user-specific signals. Alternately, Blind Multi-User Detection (BMUD) computational techniques based on the Natural Gradient Blind Source Recovery (BSR) techniques in both feedback and feedforward structures can be used. The "quasi-orthogonality" of the spreading codes and the inherent "independence" among the various transmitted user symbol sequences form the basis of the proposed BMUD methods. The inventive structures and computational techniques demonstrate promising results as compared to the conventional techniques comprising, e.g., Match Filter (MF), RAKE and block LMMSE. The inventive computational techniques can be implemented either using the batch or

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the more computationally efficient instantaneous update methods. Although batch implementations exhibit better performance, it is however accompanied by longer latency and more involved implementation structures not suitable for a UE/MS. Focus is placed on the instantaneous (or on-line) performance of the BSR computational techniques only, which still exceeds the performance of other approaches.

[0005] This (on-line) detection technique can be easily extended to other CDMA implementations, using relatively short scrambling codes, but becomes impractical in WCDMA downlink using long scrambling codes. In spite of the fact that very low bit error rates (BER) can be achieved with this technique and the detection process does not even require the knowledge of user's own signature code, the recovered signal stream is at the symbol level with no user identification. Further, inherent sign and permutation ambiguities exist in BSR (scaling is not relevant as the recovered streams are either BPSK or QPSK etc.); therefore user identification is not possible unless some preamble or pilot data is transmitted periodically. This periodic requirement stems from the dynamic nature of the wireless communication scenario where users may dynamically enter or exit the system. The environment structure also varies widely due to the mobility of the MS/UE.

[0006] With these practical constraints in mind, new computational techniques are proposed by an infusion of info-theoretic learning computational techniques such as static Blind Source Recovery (BSR) (or Independent Component Analysis, ICA) and Principal Component Analysis (PCA) in the existing

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structure of a RAKE receiver. The purpose of this additional info-theoretic stage is to counter, as best as possible, the unmodeled multiple access interference (MAI) and the additive (white Gaussian) noise in the channel. Further, use of a simple info-theoretic stage does not make the receiver structure too complex (in fact, it is simpler than most other proposed adaptive LMMSE implementations. RAKE-PCA uses up to second order statistics, as compared to RAKE-BSR, which utilizes higher order statistics. This results in slightly simpler update structure for the RAKE-PCA, but the performance of the RAKE-BSR is found to be better than RAKE-PCA. Further, assuming the score-function for the ICA update law to be chosen properly, the resulting equalization matrix in case of RAKE-BSR has relatively smaller element values (energy) as compared to the corresponding matrix for RAKE-PCA, which can be translated to the need of fewer memory bits. Lastly, both RAKE-BSR and RAKE-PCA use all the available user information, so that there are no issues of user identification and sign ambiguities in this case. The main advantage of both the RAKE-BSR and RAKE-PCA computational techniques is the improved BER performance for the UE/MS without the need of any additional information than what a standard RAKE receiver already has. The proposed computational techniques can be applied to both generic DS-CDMA and modern 3G UMTS implementations.

[0007] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the

preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0009] Figure 1 is a block diagram illustrating a signal generation model for a QPSK DS-CDMA system;

[0010] Figure 2 is a block diagram illustrating a feedforward demixing structure in accordance with a first embodiment of the present invention;

[0011] Figure 3 is a block diagram illustrating a feedback demixing structure in accordance with a second embodiment according to the present invention; and

[0012] Figure 4 is a is a block diagram illustrating a feedback demixing structure in accordance with a third embodiment according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013] The following description of the preferred embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

[0014] The present invention includes three embodiments of demixing structures providing new MUD detection systems and methods, and two new types detectors using BSR techniques. The new MUD detection systems and methods

are discussed as Natural Gradient Blind Multi-User Detection (BMUD) computational systems and methods. The two new detectors are RAKE-Blind Source Recovery (RAKE-BSR) and RAKE-Principal Component Analysis (RAKE-PCA) Detectors. These detection systems, methods, and detectors are discussed with reference to a convenient convolutive signal model representation of DS-CDMA systems discussed with reference to Figure 1.

[0015] In a typical downlink synchronous DS-CDMA system employed for indoor ATM and certain ad-hoc wireless networks, each user's data 10 is spread using an individual signature waveform (or spreading code), then the data 10 for all users is combined and transmitted over multipath AWGN channel 12 by the Base Station (BS) 14. Each User Equipment (UE) or Mobile station (MS) synchronizes itself with the BS using the broadcast synchronization/pilot channels, once synchronized the BS and UE/MS can communicate on the traffic channel (comprising of both data and control streams). Assuming the data transmission to be QPSK, i.e., comprising of two composite data channels created by a serial-to-parallel (S/P) stage, which are constellated in quadrature. At the UE/MS receiver, the received signal is first passed through a chip-matched filter and sampled at chip rate.

[0016] Considering a total of K active users in an L multipath environment and N transmitted symbols during the observation frame T_F, the received signal is given by

$$r(t) = \sum_{n=1}^{N} \sum_{k=1}^{K} \sum_{l=0}^{L-1} \sqrt{\varepsilon_{kn}(t)} b_k(n) h_l(t) s_k(t - nT - \tau_l) + n(t) \tag{1}$$

where ε_{k_n} is the energy of the nth symbol for the kth user, $b_k(n)\in\{\pm 1\pm i\}$ is the nth complex symbol for the kth user, h_l and τ_l are the lth path's gain co-efficients and delay, respectively. $n(t)$ is the additive noise and $s_k(t)$ is the kth user's signature code (or spreading sequence) generated by

$$s_k(t) = \sum_{m=0}^{G-1} \alpha_k(m)p(t - mT_c); \quad \alpha_k(m)\in \{-1,1\}; \; 0 \le m \le G-1 \qquad (2)$$

$\alpha_k(m)$ is a real spreading sequence (i.e., any of the standard CDMA PN codes, such as the Gold, Walsh-Hadamard, Kasami etc.) sequence for the kth user containing G chips per symbol, i.e., $G = T_b/T_c$. $p(t)$ is a chipping pulse of duration T_c. T_b being the symbol period.

[0017] Under the assumption of time-invariance, the model (1) can be more compactly written in a vector-matrix format at

$$\bar{r} = HS\bar{b} + \bar{n} \qquad (3)$$

where, H is a $(NG + L - 1) \times NG$ multipath propagation co-efficient matrix containing the channel coefficients. S is a $NG \times NG$ block diagonal matrix with the matrix of spreading codes forming the diagonal elements, $\bar{b}$ is an NG -d vector containing the user symbols, while $\bar{n}$ is the $(NG + L - 1)$-d channel noise vector with covariance matrix Q. The structure of the above defined matrices and vectors is given by

$$\begin{bmatrix} h_0 & 0 & \cdots & 0 \\ \vdots & \ddots & & \vdots \\ h_{L-1} & & \ddots & 0 \\ 0 & & \ddots & h_0 \\ \vdots & & \ddots & \ddots & \vdots \\ 0 & & \cdots & 0 & h_{L-1} \end{bmatrix}$$

$$S = diag\left[\overline{S}\ \overline{S} \cdots \overline{S} \right], \overline{S} = \left[s_1\ s_2 \cdots s_k \right]$$

$$\overline{b} = \left[b(1)^{\mathrm{T}}\ b(2)^{\mathrm{T}} \cdots b(\mathrm{N})^{\mathrm{T}} \right]^{\mathrm{T}}, b(n) = \left[\sqrt{{}^{\varepsilon}1n^b}\, 1(n)\ \sqrt{{}^{\varepsilon}2n^b}\, 2(n) \cdots \sqrt{\varepsilon_{kn}} b_K(n) \right]^{\mathrm{T}}$$

[0018] The compact linear model (3) is useful in deriving the linear detectors such as matched filter (MF), linear minimum mean squared error (LMMSE) etc. for recovery of the transmitted symbol train for a desired user. However, the primary disadvantage of this model is the prohibitive dimensions of the constituent matrices, especially with longer frame durations and larger G, the matrices become excessively large, making this model unsuitable for any real-time implementation at UE/MS.

[0019] Alternately, the signal model can be represented as a linear convolutive model, i.e., during symbol time, the received chip data is constituted of the chips corresponding to the currently transmitted symbol and its delayed multipath components as well as delayed chips from some previously transmitted symbols and the channel added noise. In this formulation, G chips arriving at the UE/MS during the nth symbol time are computed as the sum of the chips from L multipaths of the nth transmitted symbol and the multipath components of the previous J-1 symbols $(n-1,\ldots,n-J-1)$, where

$$J = \left| \tau_L \middle/ G \right| + 1 \tag{4}$$

τ_L being the maximum chip delay in L multipaths. The nth received symbol can be expressed as

$$r_n(t) = \sum_{k=1}^{K} b_k(n)\sqrt{\varepsilon_{kn}(t)}\sum_{l=0}^{L-1} h_l(t)s_k(t - nT - \tau_l) + n_n(t) +$$

$$\sum_{j=1}^{J-1} \sum_{k=1}^{K} b_k(n-j)\sqrt{\varepsilon_k(n-j)^{(t)}}\sum_{l=0}^{L-1} h_l(t)s_k(t - (n-j)T - \tau_l); nT \le t \le (n+1)T \tag{5}$$

[0020]   Under the assumption $L \le G$, the above model can be expressed just in terms of the current and the preceding symbol. That is, the multipaths with delay greater than symbol period either do not exist or are weak enough to be ignored. In this case, the output samples of the chip-matched filter can be written as:

$$r_n = \sum_{k=1}^{K} \left[b_{kn}\sqrt{\varepsilon_{kn}(t)}\sum_{l=0}^{L-1} h_l \overline{z}_{kl} + b_{k,n-1}\sqrt{\varepsilon_{k,n-1}(t)}\sum_{l=0}^{L-1} h_l \underline{z}_{kl} \right] + n_n \tag{6}$$

where, $\overline{z}_{kl}$ and $\underline{z}_{kl}$ are G-d early and late code vectors, i.e.,

$$\overline{z}_{kl} = \left[\underbrace{0 \cdots 0}_{\tau_l} \ s_k[1] \ \cdots \ s_k[G - \tau_l] \right]^T \tag{7}$$

$$\underline{z}_{kl} = \left[s_k\lfloor G - \tau_l + 1 \rfloor \ \cdots \ s_k[G] \underbrace{0 \cdots 0}_{G - \tau_l} \right]^T \tag{8}$$

τ_l is the discretized delay satisfying the constraint $0 \le \tau_l \le T_b$. Imposing time invariant constraints, the multipath slowly fading environment model (6) can be represented in the form

$$r_n = H_0 b_n + H_1 b_{n-1} + n_n \tag{9}$$

where b_n and b_{n-1} are the $K-d$ vectors of current and previous symbol for all the K users. H_0 and H_1 are $G \times K$ mixing matrices with the structure

$$H_0 = \lfloor H_{0,0} \quad H_{0,1} \quad \cdots \quad H_{0,K} \rfloor, H_1 = \lfloor H_{1,0} \quad H_{1,1} \quad \cdots \quad H_{1,K} \rfloor$$

such that

$$H_{0,k} = \sqrt{\varepsilon_0} \sum_{l=0}^{L-1} h_l \bar{z}_{kl} \qquad (10)$$

$$H_{l,k} = \sqrt{\varepsilon_1} \sum_{l=0}^{L-1} h_l \underline{z}_{kl} \qquad (11)$$

[0021] and $\varepsilon_{0,} \varepsilon_1$ represent the energy of the current and the previous symbol respectively.

[0022] The Natural Gradient Blind Multi-User Detection (BMUD) system and method is discussed below with reference to Figures 2-4. Blind Multi-user Detection (BMUD) is the process to blindly estimate all the user symbol sequences directly from the received composite CDMA signal using the Blind Source Recovery (BSR) techniques. BSR framework implies recovery of original signals from environments that may include transient, convolution and even non-linearity. The linear BSR computational techniques have been developed for linear convolutive mixing environments by the minimization of mutual information (Kullback Lieblar Divergence) using the natural gradient subject to the structural constraints of a recovery network. The natural gradient BMUD network can be either in the feedforward or the feedback configuration, in which the proposed BMUD system and method adaptively estimates a set of matrices to counter the linear convolutive environment model (9). In each case, an input receiveseither the linear convolutive

environment model r_n or a whitened version r_n^w of the linear convolutive environment model r_n. Parametric matrices 16A-16C W_0 and W_k are adaptable to estimate independent user symbols y_n at an nth instant based on the linear convolutive environment model r_n or the whitened version r_n^w of the linear convolutive environment model r_n. A decision stage 18 interprets y_n and estimates corresponding user symbol estimates $\hat{b}_n$ also at the nth instant.

[0023]   The justification for BMUD computational techniques is based on the convenient convolutive signal model representation of DS-CDMA systems, see (9), and the reasonable assumption that the various transmitted user symbol sequences are mutually "independent" as they are generated independently of each other. In this framework, both the transmitted sequence and the mixing matrices in the model (9) are unknown to the user. The only known entity to the user is the self-identification code. Other available prior information is the nature of transmitted data, which is assumed to be quaternary sub-guassian distribution, e.g., QPSK data distorted by the mutipath channel and additive noise. There exists enough information to apply the info-theoretic natural gradient Blind Source Recovery (BSR) system and method for BMUD in this case.

[0024] Further assume that the DS-CDMA channel is not over-saturated and $K \leq G$. The proposed BMUD computational techniques do not require any pre-whitening of received data. However, in most modern WCDMA, G is chosen to be very large and in general $K < G$. Therefore, it is computationally advantageous to pre-process received data for dimension reduction to K which is the actual number

of principal independent symbol sequences (or users) in the received data. The process of pre-whitening will also remove the second order dependence among the received data samples and some of the additive noise. The data pre-whitening can be achieved either online using adaptive principal component analysis (PCA) computational techniques or it may be done Using an algebraic PCA estimate over a large batch (say *N* samples) of received data, i.e.,

$$R = \begin{bmatrix} r_1 & r_2 & \cdots & {}^{r}N-1 & {}^{r}N \end{bmatrix}$$

with the correlation matrix

$$\Lambda_C = \frac{1}{N-1} RR^T$$

Then the whitening is achieved using the filtering matrix

$$W = D^{-1/2}V^T$$

where

D: represents the *K*-dim matrix of principle eigenvalues of the data correlation matrix Λ_C.

V: represents the *K*xM matrix of principle eigen vectors of the data correlation matrix Λ_C.

[0025]   The whitened version of (9) is given by

$$r_n^w = W(H_0 b_n + H_1 b_{n-1} + n_n) \cong \overline{H}_0 b_n + \overline{H}_1 b_{n-1} \tag{12}$$

where r_n^w represents the $G-d$ whitened data received during the nth symbol time and $\overline{H}_0, \overline{H}_1$ represent the equivalent $G \times K$ convolutive mixing matrices for the current and the previous symbol.

[0026] BMUD computational techniques blindly adapt a set of matrices to estimate the independent user symbols y_n at the nth instant. This is followed by a decision stage to interpret, as best as possible, y_n and estimate the corresponding user symbol estimates $\hat{b}_n$ also at the nth instant.

$$\hat{b}_n = \psi(y_n) \tag{13}$$

where $\psi(\cdot)$: represents the (nonlinear) decision stage.

[0027] For the feedforward configuration discussed with reference to Figure 2, the BMUD stage output is computed as

$$y_n = W_0 r_n^w + \sum_{k=1}^{K} W_k r_{n-k}^w \tag{14}$$

[0028] The update laws for this feedforward structure can be derived. For the feedforward parametric matrices W_0 and W_k, the update laws are

$$\Delta W_0 \propto \left(I - \varphi(y_n) y_n^H\right) W_0 \tag{15}$$

and

$$\Delta W_k \propto \left(I - \varphi(y_n) y_n^H\right) W_k - \varphi(y_n)\left(r_{n-k}^w\right)^H \tag{16}$$

where $\varphi(\cdot)$ is an element-wise acting score function, and I is a $K - d$ identity matrix.

[0029] For the initialization of the computational technique, W_0 is chosen to be either an identity or a diagonally dominantly matrix, while all other matrices W_k are initialized to have either random elements with a very small variance or as a

matrix of all zeros. Note that no matrix inversion is required for the feedforward computational technique.

[0030] In a second embodiment discussed with reference to Figure 3 and hereinafter referred to as feedback configuration I, the output is estimated by

$$y_n = W_0^{-1}\left(r_n^w - \sum_{k=1}^{K} W_k y_{n-k} \right) \tag{17}$$

The update law for this structure using the natural gradient are given for the matrix W_0 by

$$\Delta W_0 \propto -W_0\left(I - \varphi(y_n)y_n^H \right) \tag{18}$$

While for the feedback matrices W_k, the update law is

$$\Delta W_k \propto W_0\left(\varphi(y_n)y_{n-k}^H \right) \tag{19}$$

The matrices in this case are also initialized in a fashion similar to the feedforward case. However, note that at least one matrix inversion is required in this formulation.

[0031] In a third embodiment discussed with reference to Figure 4 and hereinafter referred to as feedback configuration II, the feedback configuration implements the feedback structure without the need for any matrix inversion. For this feedback configuration II, the BMUD stage output is computed as

$$y_n = W_0 r_n^w - \sum_{k=1}^{K} W_k y_{n-k} \tag{20}$$

The update laws for this feedback structure are given by

$$\Delta W_0 \propto \left(I - \varphi(y_n)y_n^H \right)W_0 \tag{21}$$

$$\Delta W_k \propto \left(I - \varphi(y_n) y_n^H \right) W_k + \varphi(y_n) y_{n-k}^H \qquad (22)$$

[0032] In case the channel can be estimated, the performance of the proposed BMUD computational techniques may be adjudged by the diagonalization of the absolute value of the global transfer function. The global transfer function presents the combined effect of the complex mixing and demixing transfer functions. For the two symbol convolutive models for the case of $L \leq G$, the global transfer function for the natural gradient computational techniques in the z-domain are given by:

$$G = G_0 + G_1 z^{-1} + G_2 z^{-2} \qquad (23)$$

where, for the *feedforward* configuration

$$G_0 = W_0 \overline{H}_0 = W_0 W H_0,$$

$$G_1 = W_0 \overline{H}_1 + W_1 \overline{H}_0 = W_0 W H_1 + W_1 W H_0 \; and \qquad (24)$$

$$G_2 = W_1 \overline{H}_1 = W_1 W H_1$$

while, for the *feedback* configuration I

$$G_0 = W_0^{-1} \overline{H}_0 = W_0^{-1} W H_0,$$

$$G_1 = W_0^{-1} (\overline{H}_1 - W_1) = W_0^{-1} (W H_1 - W_1) \, and \qquad (25)$$

$$G_2 = 0$$

and for the *feedback* configuration II

$$G_0 = W_0 \overline{H}_0 = W_0 W H_0,$$

$$G_1 = W_0 \overline{H}_1 + W_1 = W_0 W H_1 + W_1 \; and \qquad (26)$$

$$G_2 = 0$$

[0033] The proposed BMUD computational techniques as formulated result in recovery of the user symbols directly. The computational techniques can be conveniently applied to DS-CDMA systems using only user-specific spreading sequences. They may also be extended to CDMA systems using relatively short scrambling codes, though the dimension o matrices may still become large for DSP implementations in a UE/MS. The WCDMA system uses long codes in the downlink, making the application of these computational techniques impractical because of the requisite dimension of the demixing network matrices.

[0034] The RAKE-Blind Source Recovery (RAKE-BSR) and RAKE-Principal Component Analysis (RAKE-PCA) Detectors are now described. RAKE-BSR and RAKE-PCA are two new proposed adaptive detectors, which utilize the same knowledge as a RAKE receiver. An info-theoretic adaptive weighting matrix of dimension $G \times G$ is introduced into the RAKE structure, which gives a big performance boost to the RAKE receiver. The performance of RAKE-BSR/RAKE-PCA exceeds the performance of LMMSE detectors under the conditions of high network congestion, imprecise channel estimation, and unmodeled inter-cellular interference etc.. The closed form structure of these proposed detectors is given by

$$\hat{\tilde{b}}_{i,RAKE-ICA/PCA} = \begin{cases} S_i^H \tilde{W} \hat{H} H \bar{r} & for\ DS-CDMA\ Systems \\ S_i^H C^H \tilde{W} \hat{H} H \bar{r} & for\ WCDMA\ Systems \end{cases} \quad (27)$$

where $\tilde{W} = diag[A\,A \cdots A]$, and A is the $G \times G$ matrix that is adaptively estimated either using static BSR (ICA) or PCA computational techniques.

[0035] It is proposed to adapt the matrix A using the natural gradient update laws. However, there exist several other methds for ICA/PCA and any other suitable method may be used for these adaptations. This blind adaptation of the A matrix has several advantages and improves the performance of the overall equalization process in several ways. Firstly, it can counter artifacts in the estimated channel co-efficients $\hat{H}$. Secondly, the channel estimation process (as in RAKE receivers) may be limited by the structure (such as number of fingers) and may estimate only a few of the dominant channel parameters. $\hat{W}$ stage tends to counteract this anomaly, as best as possible, and provides better performance than LMMSE in such cases. Thirdly, this adaptive stage minimizes the effect of the additive channel noise, which may have an unmodeled intricate underlying structure. Lastly, the natural gradient ICA/PCA computational techniques inherently reduce near-far problems by removing any ill conditioning in the signal space for all the users in the system. This results in all the mobile users in the system to have a BER performance similar to the average BER performance of the downlink channel. The matrix A is adaptively estimated using the update laws

$$A(k+1) = A(k) + \eta_k \Delta A(k) \qquad (28)$$

where

$$\Delta A(k) = \begin{cases} (I - \varphi(y(k))y(k)^H)A(k) & \text{for static BSR (or ICA)} \\ (I - y(k)y(k)^H)A(k) & \text{for PCA} \end{cases} \qquad (29)$$

and $\varphi(\cdot)$ is a nonlinear score function which depends on the underlying distribution structure of the signals involved. For QPSK signal, a suitable score-function is

$$\varphi_i(y_i) = \upsilon_i y_i - \alpha_i \left(\tanh(\beta_i \operatorname{Re}\{y_i\}) + \tanh(\beta_i \operatorname{Im}\{y_i\}) \right) \qquad (30)$$

[0036] Of these proposed RAKE-BSR/RAKE-PCA structures, RAKE-BSR exhibits relatively faster and more stable convergence. However, in CDMA systems the underlying code structure is chosen to be "orthogonal", and RAKE-PCA may converge to a slightly lower BER solution if the channel impairments are linear in nature. Note that in (27), if the channel estimate $\hat{H}$ is either not available or changes very dynamically, the detector can be estimated without using the channel estimate and the structure reduces to Matched Filter BSR/PCA, i.e.,

$$
\hat{b}_{i,MF-BSR/PCA} = \begin{cases} S_i^H \tilde{W}r & \text{for DS–CDMA Systems} \\ S_i^H C^H \tilde{W}r & \text{for WCDMA Systems} \end{cases} \tag{31}
$$

The performance of this structure is better than Matched Filter alone, and approaches RAKE performance as the underlying matrix A converges.

[0037] The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1.   A natural gradient Blind Multi User Detection (BMUD) network system that adaptively estimates a set of matrices to counter a linear convolutive environment model r_n, the system comprising:

an input receptive of at least one of the linear convolutive environment model r_n and a whitened version r_n^w of the linear convolutive environment model r_n;

parametric matrices W_0 and W_k adaptable to estimate independent user symbols y_n at an nth instant based on at least one of the linear convolutive environment model r_n and the whitened version r_n^w of the linear convolutive environment model r_n; and

a decision stage interpreting y_n and estimating corresponding user symbol estimates $\hat{b}_n$ also at the nth instant.

2.   The system of claim 1, wherein the system is networked in a feedforward configuration.

3.   The system of claim 2, wherein the decision stage is adapted to compute y_n according to:

$$y_n = W_0 r_n^w + \sum_{k=1}^{K} W_k r_{n-k}^w.$$

4. The system of claim 2, wherein the parametric matrices W_0 and W_k have update laws according to:

$$\Delta W_0 \propto \left(I - \varphi(y_n)y_n^H\right)W_0 \text{; and}$$

$$\Delta W_k \propto \left(I - \varphi(y_n)y_n^H\right)W_k - \varphi(y_n)\left(r_{n-k}^W\right)^H,$$

where $\varphi(\cdot)$ is an element-wise acting score function, and I is a $K-d$ identity matrix.

5. The system of claim 2, wherein W_0 is initially chosen to be at least one of an identity and a diagonally dominantly matrix, while all other matrices W_k are initialized to have at least one of random elements with a very small variance and as matrices of all zeros.

6. The system of claim 1, wherein the system is networked in a feedback configuration.

7. The system of claim 6, wherein the decision stage is adapted to compute y_n according to:

$$y_n = W_0^{-1}\left(r_n^w - \sum_{k=1}^{K} W_k y_{n-k}\right).$$

8.   The system of claim 6, wherein the parametric matrices W_0 and W_k have update laws according to:

$$\Delta W_0 \propto -W_0\left(I - \varphi(y_n)y_n^H\right); \text{ and}$$

$$\Delta W_k \propto W_0\left(\varphi(y_n)y_{n-k}^H\right),$$

where $\varphi(\cdot)$ is an element-wise acting score function, and I is a $K-d$ identity matrix.

9.   The system of claim 1, wherein the system is networked in a feedback configuration without need for any matrix inversion.

10.   The system of claim 9, wherein the decision stage is adapted to compute y_n according to:

$$y_n = W_0 r_n^w - \sum_{k=1}^{K} W_k y_{n-k}.$$

11.   The system of claim 9, wherein the parametric matrices W_0 and W_k have update laws according to:

$$\Delta W_0 \propto \left(I - \varphi(y_n)y_n^H\right)W_0; \text{ and}$$

$$\Delta W_k \propto \left(I - \varphi(y_n)y_n^H\right)W_k + \varphi(y_n)y_{n-k}^H,$$

where $\varphi(\cdot)$ is an element-wise acting score function, and I is a $K-d$ identity matrix.

12. The system of claim 1, further comprising a whitening filter preprocessing received data for dimension reduction to K, which is an actual number of principal independent symbol sequences in the received data, and to remove second order dependence among received data samples and additive noise.

13. The system of claim 12, wherein the whitening filter whitens data online using adaptive principle component analysis computational techniques.

14. The system of claim 13, wherein the whitening filter whitens data using an algebraic PCA estimate over a large batch of received data including N samples according to:

$$R = \begin{bmatrix} r_1 & r_2 & \cdots & r_{N-1} & r_N \end{bmatrix}$$

with a data correlation matrix

$$\Lambda_c = \frac{1}{N-1} RR^{\mathrm{T}}.$$

15. The system of claim 14, wherein the filter achieves the whitening using a filtering matrix according to:

$$W = D^{-1/2}V^T$$

where D represents a K-dim matrix of principle eigenvalues of the data correlation matrix Λ_c, and V represents a KxM matrix of principle eigen vectors of the data correlation matrix Λ_c.

16. The system of claim 12, wherein the filter is adapted to calculate the whitened version r_n^w of the linear convolutive environment model r_n according to:

$$r_n^w = W(H_0 b_n + H_1 b_{n-1} + n_n) \cong \overline{H}_0 b_n + \overline{H}_1 b_{n-1},$$

and the linear convolutive environment model r_n is represented according to:

$$r_n = H_0 b_n + H_1 b_{n-1} + n_n$$

where b_n and b_{n-1} are the $K - d$ vectors of current and previous symbol for all the K users, H_0 and H_1 are $G \times K$ mixing matrices with the structure

$$H_0 = \lfloor H_{0,0} \quad H_{0,1} \quad \cdots \quad H_{0,K} \rfloor, H_1 = \lfloor H_{1,0} \quad H_{1,1} \quad \cdots \quad H_{1,K} \rfloor \text{ such that } H_{0,k} = \sqrt{\varepsilon_0} \sum_{l=0}^{L-1} h_l \overline{z}_{kl},$$

$H_{l,k} = \sqrt{\varepsilon_1} \sum_{l=0}^{L-1} h_l \underline{z}_{kl}$, and $\varepsilon_0, \varepsilon_1$ represent the energy of the current and the previous symbol respectively.

17. An adaptive detector utilizing knowledge utilized by a RAKE receiver, comprising:

an adaptive weighting matrix introduced into a RAKE structure, wherein the matrix is adaptively estimated using at least one of Principal Component Analysis (PCA) computational techniques and static Blind Source Recovery (BSR) computational techniques based on Independent Component Analysis (ICA).

18.   The detector of claim 17, further comprising a closed form RAKE structure according to:

$$\hat{\hat{b}}_{i,RAKE-ICA/PCA} = \begin{cases} S_i^H \widetilde{W} \hat{H}^H \bar{r} & for\ DS-CDMA\ Systems \\ S_i^H C^H \widetilde{W} \hat{H}^H \bar{r} & for\ WCDMA\ Systems \end{cases}$$

where $\widetilde{W} = diag[A\ A\ \cdots A\ ]$, and A is the matrix.

19.   The detector of claim 18, wherein the matrix is adapted according to natural gradient update laws.

20.   The detector of claim 19, wherein the matrix is adaptively estimated using natural gradient update laws according to:

$$A(k+1) = A(k) + \eta_k \Delta A(k)$$

where

$$\Delta A(k) = \begin{cases} (I - \varphi(y(k))y(k)^H)A(k) & for\ static\ BSR\ (or\ ICA) \\ (I - y(k)y(k)^H)A(k) & for\ PCA \end{cases}$$

and $\varphi(\cdot)$ is a nonlinear score function which depends on an underlying distribution structure of involved signals.

21.   The detector of claim 20, wherein the score function is:

$$\varphi_i(y_i) = \upsilon_i y_i - \alpha_i \left(\tanh\left(\beta_i \operatorname{Re}\{y_i\}\right) + \tanh\left(\beta_i \operatorname{Im}\{y_i\}\right)\right).$$

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22.   The detector of claim 17, wherein a channel estimate $\hat{H}$ is at least one of not available and changes dynamically, and the detector is estimated without using the channel estimate, such that the structure reduces to Matched Filter (MF) BSR/PCA according to:

$$\hat{\tilde{b}}_{i,MF-BSR/PCA} = \begin{cases} S_i^H \tilde{W} r & \text{for DS--CDMA Systems} \\ S_i^H C^H \tilde{W} r & \text{for WCDMA Systems} \end{cases}$$

23.   A natural gradient Blind Multi User Detection (BMUD) method that adaptively estimates a set of matrices to counter a linear convolutive environment model r_n , comprising:

receiving at least one of the linear convolutive environment model r_n and a whitened version r_n^w of the linear convolutive environment model r_n ;

adapting parametric matrices W_0 and W_k to estimate independent user symbols y_n at an nth instant based on at least one of the linear convolutive environment model r_n and the whitened version r_n^w of the linear convolutive environment model r_n ; and

interpreting y_n and estimating corresponding user symbol estimates $\hat{b}_n$ also at the nth instant.

24.   The method of claim 23, further comprising employing a feedforward network configuration.

25. The method of claim 24, further comprising computing y_n according to:

$$y_n = W_0 r_n^w + \sum_{k=1}^{K} W_k r_{n-k}^w .$$

26. The method of claim 24, further comprising updating the parametric matrices W_0 and W_k via update laws according to:

$$\Delta W_0 \propto \left(I - \varphi(y_n) y_n^H \right) W_0 ; \text{ and}$$

$$\Delta W_k \propto \left(I - \varphi(y_n) y_n^H \right) W_k - \varphi(y_n) \left(r_{n-k}^W \right)^H ,$$

where $\varphi(\cdot)$ is an element-wise acting score function, and I is a $K - d$ identity matrix.

27. The method of claim 24, further comprising:

initializing W_0 to be at least one of an identity and a diagonally dominantly matrix; and

initializing all other matrices W_k to have at least one of random elements with a very small variance and as matrices of all zeros.

28. The method of claim 23, further comprising employing a feedback network configuration.

29. The method of claim 28, further comprising computing y_n according to:

$$y_n = W_0^{-1}\left(r_n^w - \sum_{k=1}^{K} W_k y_{n-k} \right).$$

30. The method of claim 28, updating the parametric matrices W_0 and W_k via update laws according to:

$$\Delta W_0 \propto -W_0\left(I - \varphi(y_n)y_n^H \right); \text{ and}$$

$$\Delta W_k \propto W_0\left(\varphi(y_n)y_{n-k}^H \right),$$

where $\varphi(\cdot)$ is an element-wise acting score function, and I is a $K-d$ identity matrix.

31. The method of claim 23, further comprising employing a feedback network configuration without need for any matrix inversion.

32. The method of claim 31, further comprising computing y_n according to:

$$y_n = W_0 r_n^w - \sum_{k=1}^{K} W_k y_{n-k} .$$

33. The method of claim 31, further comprising updating the parametric matrices W_0 and W_k via update laws according to:

$$\Delta W_0 \propto \left(I - \varphi(y_n) y_n^H \right) W_0; \text{ and}$$

$$\Delta W_k \propto \left(I - \varphi(y_n) y_n^H \right) W_k + \varphi(y_n) y_{n-k}^H,$$

where $\varphi(\cdot)$ is an element-wise acting score function, and I is a $K - d$ identity matrix.

34. The method of claim 23, further comprising preprocessing received data for dimension reduction to K, which is an actual number of principal independent symbol sequences in the received data, and to remove second order dependence among received data samples and additive noise.

35. The method of claim 34, further comprising whitening data online using adaptive principle component analysis computational techniques.

36. The method of claim 35, further comprising whitening data using an algebraic PCA estimate over a large batch of received data including N samples according to:

$$R = \left[r_1 \ r_2 \ \cdots \ 'N-1 \ 'N \right]$$

with a data correlation matrix

$$\Lambda_c = \frac{1}{N-1} R R^T.$$

37. The method of claim 35, further comprising employing a filtering matrix according to:

$$W = D^{-1/2}V^T$$

where D represents a K-dim matrix of principle eigenvalues of the data correlation matrix Λ_c, and V represents a KxM matrix of principle eigen vectors of the data correlation matrix Λ_c.

38. The method of claim 34, further comprising calculating the whitened version r_n^w of the linear convolutive environment model r_n according to:

$$r_n^w = W(H_0 b_n + H_1 b_{n-1} + n_n) \cong \overline{H}_0 b_n + \overline{H}_1 b_{n-1},$$

wherein the linear convolutive environment model r_n is represented according to:

$$r_n = H_0 b_n + H_1 b_{n-1} + n_n$$

where b_n and b_{n-1} are the $K-d$ vectors of current and previous symbol for all the K users, H_0 and H_1 are $G \times K$ mixing matrices with the structure

$H_0 = \lfloor H_{0,0} \quad H_{0,1} \quad \cdots \quad H_{0,K} \rfloor, H_1 = \lfloor H_{1,0} \quad H_{1,1} \quad \cdots \quad H_{1,K} \rfloor$ such that $H_{0,k} = \sqrt{\varepsilon_0} \sum_{l=0}^{L-1} h_l \overline{z}_{kl}$,

$H_{l,k} = \sqrt{\varepsilon_1} \sum_{l=0}^{L-1} h_l \underline{z}_{kl}$, and $\varepsilon_0, \varepsilon_1$ represent the energy of the current and the previous symbol respectively.

39.   An adaptive detection method, comprising:

introducing an adaptive weighting matrix into a RAKE structure, wherein the matrix is adaptively estimated using at least one of Principal Component Analysis (PCA) computational techniques and static Blind Source Recovery (BSR) computational techniques based on Independent Component Analysis (ICA).

40.   The method of claim 39, further comprising employing a closed form RAKE structure according to:

$$\hat{\tilde{b}}_{i,RAKE-ICA/PCA} = \begin{cases} S_i^H \tilde{W} \hat{H}^H \bar{r} & for\, DS-CDMA\, Systems \\ S_i^H C^H \tilde{W} \hat{H}^H \bar{r} & for\, WCDMA\, Systems \end{cases}$$

where $\tilde{W} = diag[\text{A A} \cdots \text{A}]$, and A is the matrix.

41.   The method of claim 40, further comprising adapting the matrix according to natural gradient update laws.

42. The method of claim 41, further comprising adaptively estimating the matrix using natural gradient update laws according to:

$$A(k+1) = A(k) + \eta_k \Delta A(k)$$

where

$$\Delta A(k) = \begin{cases} (I - \varphi(y(k))y(k)^H)A(k) & \text{for static } BSR\,(or\,ICA) \\ (I - y(k)y(k)^H)A(k) & \text{for } PCA \end{cases}$$

and $\varphi(\cdot)$ is a nonlinear score function which depends on an underlying distribution structure of involved signals.

43. The method of claim 42, further comprising employing a score function according to:

$$\varphi_i(y_i) = \upsilon_i y_i - \alpha_i \left(\tanh\left(\beta_i \operatorname{Re}\{y_i\}\right) + \tanh\left(\beta_i \operatorname{Im}\{y_i\}\right) \right).$$

44. The method of claim 39, wherein a channel estimate $\hat{H}$ is at least one of not available and changes dynamically, the method further comprising estimating a detector without using the channel estimate, such that the detector structure reduces to Matched Filter BSR/PCA according to:

$$\hat{\tilde{b}}_{i,MF-BSR/PCA} = \begin{cases} s_i^H \tilde{W}r & \text{for } DS-CDMA\,Systems \\ s_i^H C^H \tilde{W}r & \text{for } WCDMA\,Systems \end{cases}.$$

ABSTRACT OF THE DISCLOSURE

A natural gradient Blind Multi User Detection (BMUD) network system and method adaptively estimates a set of matrices to counter a linear convolutive environment model. Feedforward and feedback network structures may be implemented, with or without matrix inversion. In other aspects, an adaptive weighting matrix is introduced into a RAKE structure, and the matrix is adaptively estimated using Principal Component Analysis (PCA) computational techniques and/or static Blind Source Recovery (BSR) computational techniques based on Independent Component Analysis (ICA).
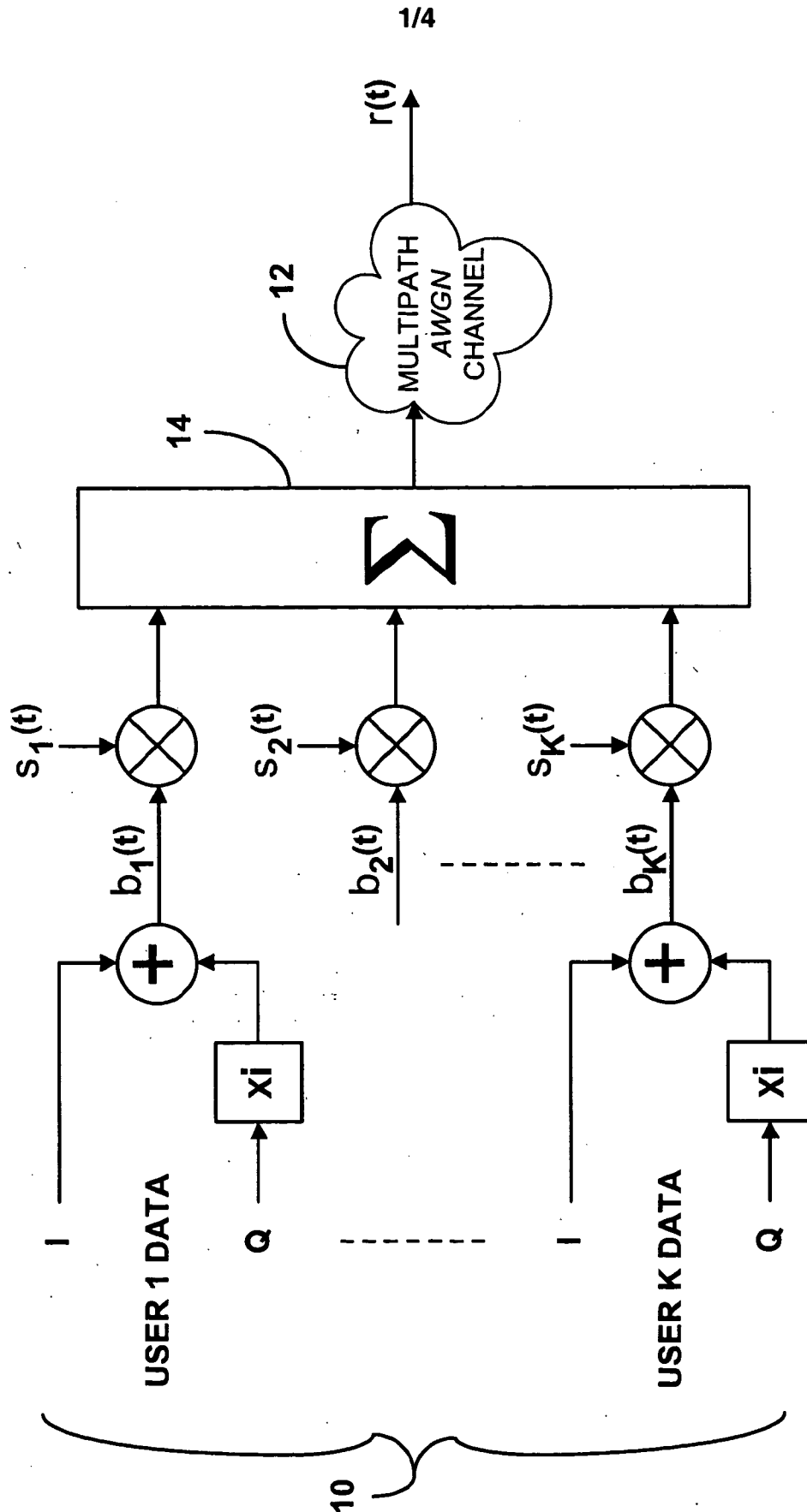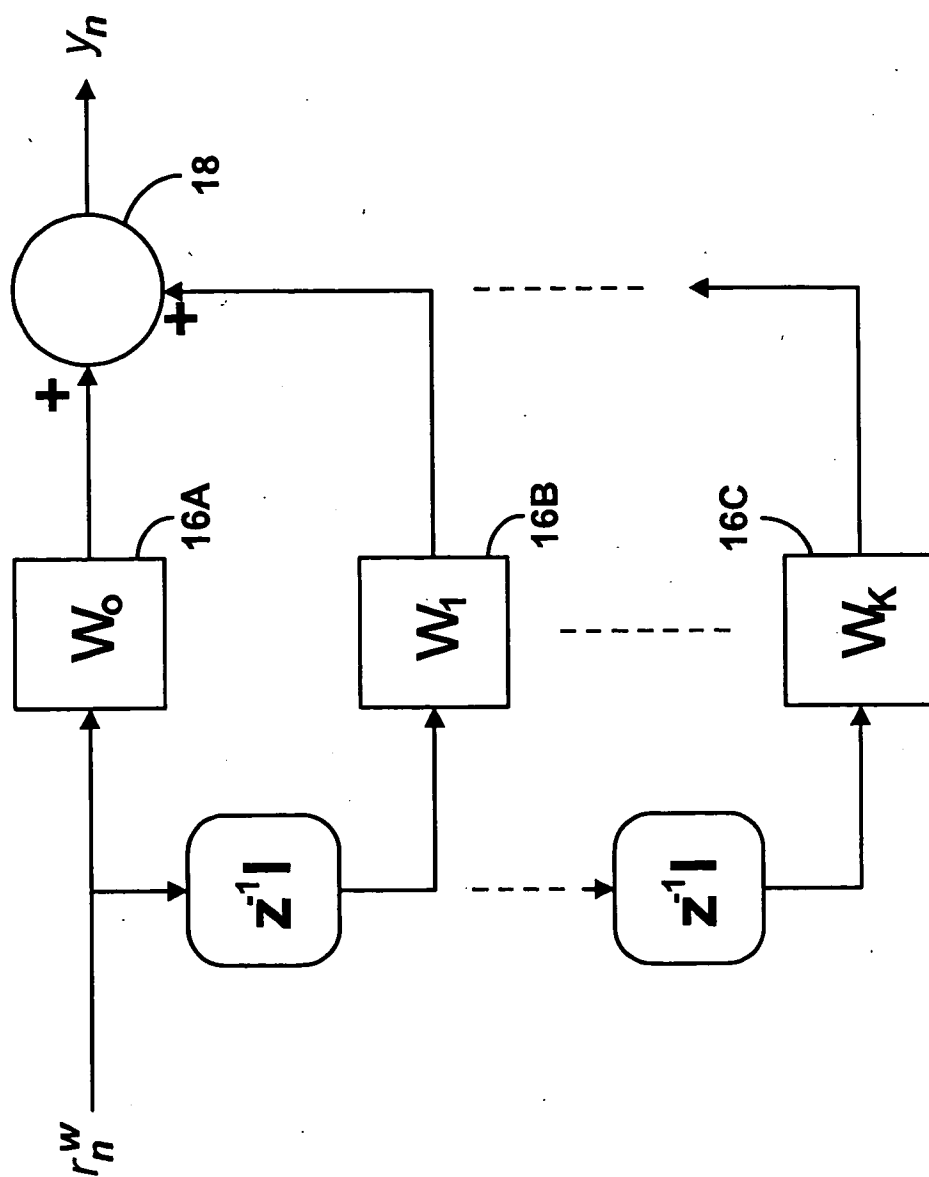
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Inventors: Fathi M. Salem, et al.
Atty. Ref.: 6550-000087

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**Figure - 1**

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Figure - 2

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Figure - 3

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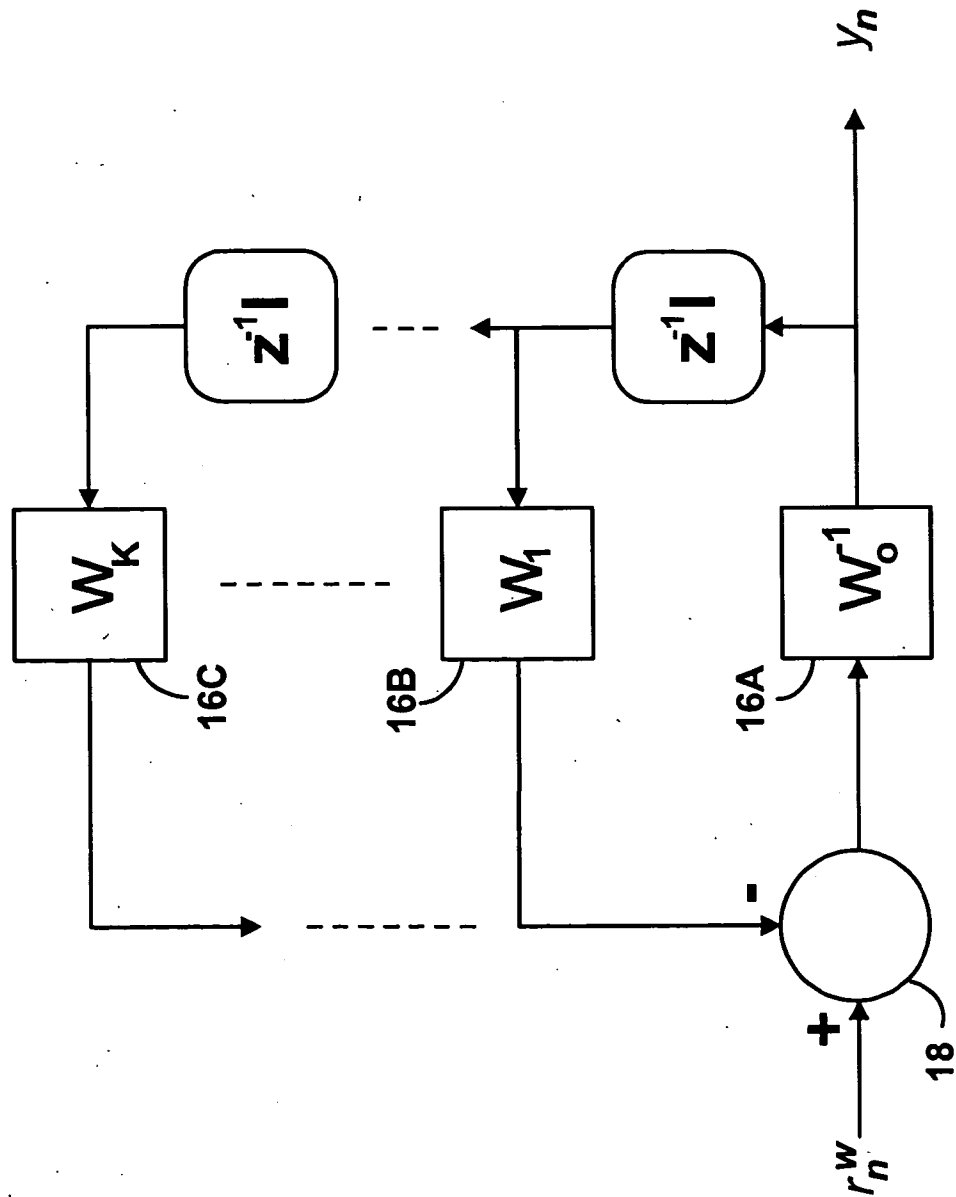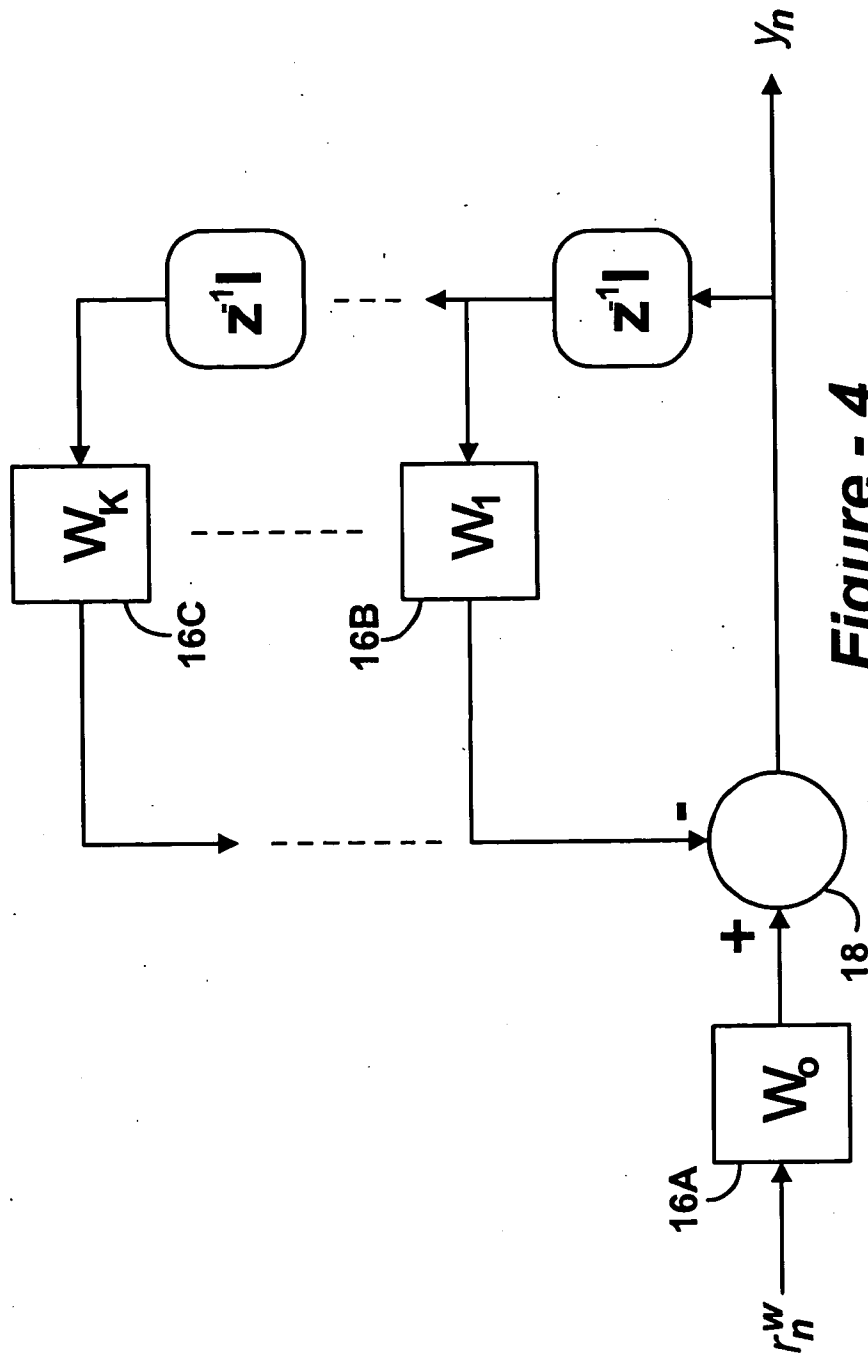*Figure - 4*

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